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Analyze the Effect of Weld Heat Input on Mechanical Properties of Nitrogen Alloyed Stainless Steel by GMAW Process

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Abstract: *GMAW process in the recent research work investigates the effect of heat input, feed rate, voltage, current (controlled by GMAW Process) on the tensile strength, micro-hardness and microstructure of nitrogen alloyed stainless steel (JT grade). The base material used for the investigation was Nitrogen Grade austenitic stainless steel (JT Grade) with the low percentage of nickel content. JT grade steel has good resistance to oxidation, easy fabrication, and excellent toughness even in the low temperatures. It is not expensive as lower cost nitrogenand manganese are added as partial alternative for nickel. The yield and ultimate tensile strength of the base metals and welding filler was to be calculated to get the best desirable properties of the welding process. The microstructure, macro-structure and chemical test onthe metal plates were done to study about their properties. The numbers of trials are to be donefor getting the best and appropriate parameters. And the last testing were done on the best parameters(heat input, voltage, current) on the base metal of JT grade to test the micro- hardness and tensile strength of the metal and welding. The 3 types of filler metal ER308L, ER309L, and ERNiCrMo3 were used during the welding process in GMAW to study these effects. The hardness were tested at the HAZ area and WELD area and the location of fracture from welding area were consider during the testing to get the tensile strength of the weld.*

Keywords: GMAW, UTS, Hardness, Taguchi method, Microstructure analysis, filler metal electrode

I. INTRODUCTION

GMAW process is based on the principle of developing weld by melting faying surfaces of thebase metal using heat produced by a welding arc established between base metal and a consumable electrode. Welding arc and weld pool are well protected by a jet of shielding inactive gas coming out of the nozzle and forming a shroud around the arc and weld. MIG weld is not considered as clean as TIG weld. Difference in cleanliness of the weld producedby MIG and TIG welding is primarily attributed to the variation in effectiveness of shielding gas to protect the weld pool in case of above two processes. Effectiveness of shielding in two processes is mainly determined by two characteristics of the welding arc namely stability of the welding arc and length of arc besides other welding related parameters such as type of shielding gas, flow rate of shielding gas, distance between nozzle and work-price. The MIG arc is relatively longer and less stable than TIG arc. Difference in stability of two welding arcsis primarily due to the fact that in MIG arc is established between base metal and consumable electrode (which is consumed continuously during welding) while TIG welding arc is established between base metal and non-consumable tungsten electrode. Consumption of the electrode during welding slightly decreases the stability of the arc. Therefore, shielding of the weld pool in MIGW is not as effective as in TIGW.

1.1 Austenitic stainless steels

Austenitic stainless steels have a face centered cubic (FCC) crystal structure at room temperature. They are usually non-magnetic in nature but can become slightly magnetic under certain conditions. These steels are able to hardened and strengthened by cold work (e.g., rolling, bending or otherwise deforming the steel), but not applied by heat. These

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stainless steels have good strength at elevated temperatures, stability at cryogenic temperatures and ease of fabric ability including weldability. The austenitic stainless steels constitute the largest group of stainless steels in use, making up 65 to 70 % of the total. Austenitic stainless steels are generally available in two series, AISI 200 and 300 series. AISI 200 series include grades 201, 202 and 205 etc., whereas AISI 300 series include grades 301, 302, 304, 304L, 316, 316 L, 321, 347 etc. and containing chromium 18-25 wt% and nickel 8-20 wt%. Some of these grades have also been researched for their bio-functionality where they have been used for fabricating artificial femur stems.

II. LITERATURE REVIEW

J M kenny et. al. [1] studied the relationship between microstructures and mechanical properties of a high nitrogen stainless steel (containing about 1% Ni and 0.37% N) with an ultrafine grained structure. Nitrogen alloyed austenitic stainless steels exhibit attractive properties such as high strength and ductility, good corrosion resistance and reduced tendency of grain boundary sensitization. 304 stainless steel with an average grain size of ca. 0.8Amwas obtained by applying the reverse transformation of martensite to austenite, in subzero- worked steel, annealed at low temperatures. They observed that grain refinement was achieved down to 2.5 µm grain size. The dependence of the tensile yield strength, the hardness and the elastic modulus of the steel in the grain size followed the Hall-Petch relationship throughout the full analyzed range.

Apurv Choubey et. al. [2] They examine that the Austenitic steels have austenite as their primary phase with face centered cubic crystal. As these alloys constitutes single phase, they can be strengthened by work hardening or solid solution alloying. They find application inboth mild and severe corrosive condition due to presence of chromium in austenitic stainless steel. Present research work investigates the effect of heat input (controlled by welding current, welding voltage and welding speed) on tensile strength, micro-hardness and microstructure of austenitic 202 grade stainless steel weldments produced by shielded metal arc welding (SMAW). The base material used in the present investigation was Cr-Mn SS and 308L SS solid electrode was used as the filler material. From the experimental results it was found that the increase in heat input affects the micro-constituents of base metal, and heat affected zone (HAZ).

J W Simmons [3] Observed that High-strength austenitic stainless steels can be produced by replacing carbon with nitrogen. Nitrogen has greater solid-solubility than carbon, is a strong austenite stabilizer, potent interstitial solid-solution strengthener, and improves pitting corrosion resistance. And found that the limitation of producing high-nitrogen steels, owing to the low nitrogen solubility in liquid iron-based alloys at atmospheric pressure, has been overcome through the use of pressurized-melting technologies. Thus, alloys with N levels exceeding 1 wt.% can be commercially produced. Production of high-nitrogen stainless steels via powder metallurgy routes is technically possible and economically attractive, since the total solubility of nitrogen in stainless steels is higher in the solid state than in the liquid and capital expenditures are lower for powder metallurgy processing than for high pressure melting technologies.

Byrnes et. al. [4] has discussed that the low-temperature flow stress of mechanically stable austenitic stainless steels increases with increasing concentration of nitrogen in solution and with decreasing temperature. This phenomenon has been studied in a series of Fe-NiXr-Mo alloys with nitrogen contents between 0.04 and 0.36 wt% by measuring the flow stress and the thermal activation parameters for plastic flow as a function of stress, plastic strain and nitrogen concentration in stress relaxation and strain-rate change experiments. Care is taken, when analyzing the data, to distinguish between a thermal and thermal effects. And found that no evidence was found to suggest that nitrogen strengthening of Fe-26Cr32Ni alloys is influenced significantly by magnetic effects.

C H Shek et. al. [5] has studied the developments in conventional stainless steels, those in the high-nitrogen, low-Ni (or Ni-free) varieties are also introduced. These recent developments include new methods for attaining very high nitrogen contents, new guidelines for alloy design, the merits/demerits associated with high nitrogen contents, etc. and find that Although the use of stainless steels has had a long history, there are still a lot of problems that remain unresolved. For instance, the newly discovered J phase, except in the series of papers written by its discoverers, is not commonly reported by others. Although the effects of this phase on mechanical properties have been studied by its discoverers, it seems that its effects on corrosion and magnetic properties have not been thoroughly investigated.

2.1. Objective of Research

The objective of the research is to find the effect of the mechanical properties and microstructure on the nitrogen alloy steel. Many types of steels are used in the world, some of them are even costly and some of them are cheap. Different properties and chemical composition makes the new metal in this field which is made suitable according to the consumer.

1 The research is on the effect of mechanical properties of nitrogen alloy steel which we have taken as the low cost nitrogen alloy stainless steel JT grade which is cheap in costand has good mechanical properties. Due to the content of Nitrogen the stainless steel metal has good corrosive properties.
2 To find the effect of different parameters after welding on the plates of this metal we will get to know about the value of this metal and will show that this metal is very reliable and cost effective for the further use.
3 The tensile test, microstructure, macrostructure and chemical test studies are to be done after the welding of these metal plates using 3 different electrodes. Er3058L,Er309L and NiCrMo3.
4 To get the best heat input and feed rate parameter in welding of base metal which is tested at different parameter will give us the suitable conclusion which is discuss on the UTS value of the metal after welding.

III. MACHINE AND CONSUMABLES

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt and join.
Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed- spray, each of which has distinct properties and corresponding advantages and limitations.

3.1. Equipments

To perform gas metal arc welding, the basic necessary equipments

- Welding Gun,
- Wire Feed Unit,
- Welding Power Supply
- Welding Electrode Wire,
- Shielding Gas Supply.

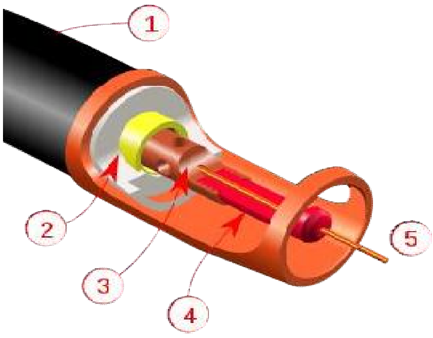

Figure 3.1 GMAW torch nozzle cutaway image. (1) Torch handle, (2) Molded phenolicdielectric (shown in white) and threaded metal nut insert (yellow), (3)Shielding gas diffuser, (4) Contact tip, (5) Nozzle output face[20]

Electrode used during the experimental setup-

- ER308L
- ER309L
- ERNiCrMo3

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3.2. JT Grade Austenitic Stainless Steel

JT Grade Sheets is a JT is a cost effective austenitic stainless steel with high strength it has low-Nickel content and known as from the family of nitrogen alloy austentic stainless steel. The steel has good corrosion resistance in mildly corrosive environments and good resistance to oxidation at elevated temperatures.

IV. EXPERIMENTAL PROCEDURE

We setup the whole GMAW machine in Central Institute of Petrochemicals Engineering & Technology (CIPET) lab for the welding process of test pieces. In the GMAW machine we used 3 different electrodes (ER308L, ER309L, ERNiCrMo3) were used and trials were done on these electrodes to get the best parameters.

Figure 4.1: Mechanized torch setup of GMAW setup in CIPET Lucknow

Torch setup was done by using clamp and fixed on mechanized system to provide constant traveling speed of torch for getting a linear form of welding. The distance between the torch and the base metal is 10 mm.

Figure 4.2: GMAW setup for welding in CIPET Lucknow

Using the GMAW process we tested the trial pieces on the different parameters(voltage, current, feed rate, speed) to find the best result on the heat input for the welding.

Elements	%C	%Mn	%S	%P	%Si	%Ni	%Cr	%Cu	%N
Min	-	9.75	-	-	-	0.40	14.0	0.40	
Max	0.13	11.0	0.015	0.1	0.75	-	15.25	-	0.2

4.1. The trials from number 01 to 09 were done by using filler metal ER308L

Table 4.1 Trials results

Trial no.	Voltage(V)	Current(A)	Feed rate (m/min)	Speed(mm/min)	Heat input Kj/mm
1	11.5	75	2	200	0.25875
2	12.5	89	2.5	200	0.333
3	13.00	112	3.0	200	0.4368
4	14.0	145	3.5	230	0.529
5	14.5	155	4.0	260	0.518
6	15.5	175	4.5	260	0.6259
7	16	190	5.0	300	0.608
8	13	130	4.3	260	0.365
9	15	180	6.3	220	0.736

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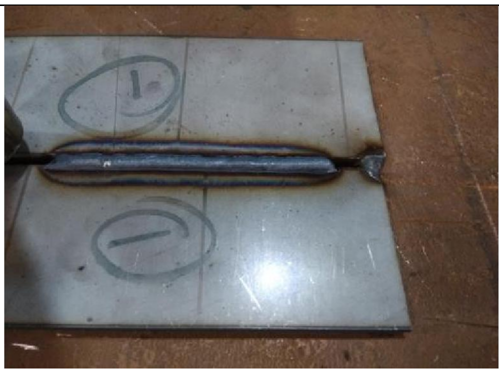
Trial pieces are tested on the different parameters before testing on the main coupons by using 3 different electrodes. After testing these trial we get the best 3 parameters on high, medium, low inputs



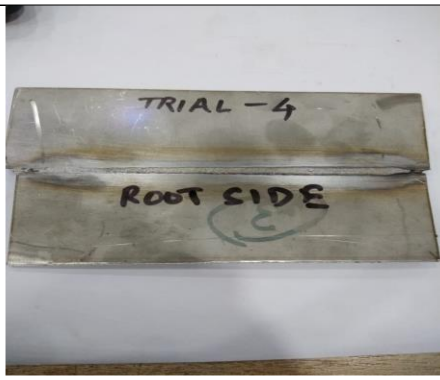



Table 4.2 Trials tested on different parameters on electrode ER308L

After testing on trials with the filler metal ER308L we get the final parameters on which we have taken for the final sample. The test coupon plate size of 300mm×250mm were welded by the GMAW welding process at 3 different parameters .

Table 4.3 Final parameters of test coupon-01 to 09

Test Coupon	Voltage(V)	Current(A)	Feedrate (m/min)	Speed(mm/min)	Heatinput Kj/mm
01	14	110	3.4	250	0.3696
02	15	150	5.2	240	0.5624
03	15	180	6.3	200	0.815

04	14	120	3.3	245	0.411
05	15	140	4.0	224	0.562
06	16	170	4.9	200	0.816
07	18	180	6.3	220	0.8717
08	17	130	4.3	250	0.536
09	20	190	6.7	200	1.14

After getting the final test coupons results, the test coupons 01 to 09 were send for the further testing of microstructure and macrostructure, tensile strength and chemical. In the result we will see the different mechanical properties of all the test coupons.

4.2. Taguchi Orthogonal Array Selection

The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality. Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the loss function is further transformed into signal-to-noise (S/N) ratio.

4.2.1. Experimental Parameter

Input parameters: Voltage (V), Current (A), Feed rate (m/min), Speed(mm/min), and Heat input (Kj/mm).
Output parameters: Tensile strength and Hardness

Table -4.4: Control Factors and their level

Sr.No.	Welding Parameters	Symbol	Levels		
			1	2	3
1	Voltage (V)	A	14	17	20
2	Current (A)	B	110	150	190
3	Feed rate (m/min)	C	3.4	5	6.6
4	Speed(mm/min)	D	250	225	200
5	Heat input (Kj/mm)	E	0.3696	0.7548	1.14

4.2.2. Proposed Design of Experiment

For performing the experiments Taguchi L27 orthogonal array was selected for 5-factor and 3-level process parameters and which reduces the number of experimentswhich is given in table 4.4.

Taguchi Design

Design Summary

Taguchi Array:	L27(3^5)
Factors:	5
Runs:	27

Columns of L27(3^13) array: 1 2 3 4 5

V. RESULT AND DISCUSSION

In this project it was intended to experimentally investigate the effect of various parameters (heat input, feed rate, voltage, current (controlled by GMAW Process) on the Nitrogen alloy stainless steel (JT grade). The tensile strength, micro-hardness, microstructure and chemical test of nitrogen alloyed stainless steel (JT grade) were done after the welding process of two plates of same base metal. This project was completed in following steps:

1 Commercially available Nitrogen alloy stainless steel (JT grade) of thickness 3mm was taken as the base material for the experiment.
2 Plates were prepared according to required dimension.
3 Selection of tool and tool design.
4 Factor selection to optimize process parameter using GMAW method.
5 Testing of mechanical properties like tensile strength, microstructure, and microhardness of base material as well as processed plate.

Figure 5.1 Sample prepared for micro hardness testing

5.1 Hardness Test Results

In order to study the variation of hardness across base metal, HAZ and welded part, three testcoupons were prepared for each filler wire. The result obtained is shown in table

Filler 1- ER308L

Test coupon-01, test coupon-02, test coupon- 03

Test Coupon-01

Table 5.1 Hardness test for test coupon-01

Location	Hardness	Avg.(HV1)
HAZ Area	229,235,237	234
Weld Area	205,200,200	202

Test Coupon-02

Table 5.2 Hardness test for test coupon-02

Location	Hardness	Avg.(HV1)
HAZ Area	249,243,249	247
Weld Area	200,205,200	202

Test Coupon-03

Table 5.3 Hardness test for test coupon-03

Location	Hardness	Avg.(HV1)
HAZ Area	246,242,248	245
Weld Area	179,181,180	180

5.2 Tensile Strength Test

Tensile strength is to be calculated on the test coupons-(01-09)

Filler 1- ER308L

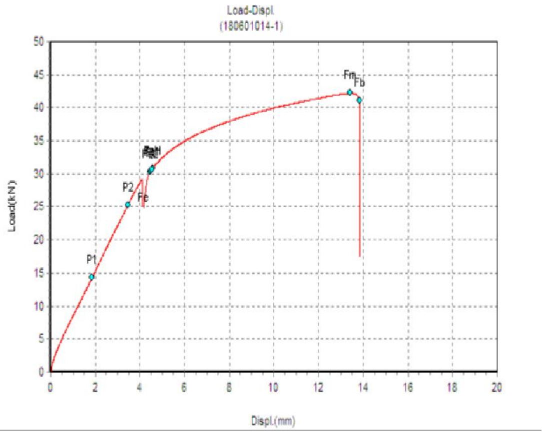
Test coupon-01, test coupon-02, test coupon- 03

Test coupon-01

Table 5.4 Tensile test for test coupon-01

Tensile Test				
Sample ID	Specimen Size (width×Thickness) mm	Cross-sectionalArea (mm2)	Tensile strengthN/mm2	Location of Fracture
1.	18.85×2.95	55.61	759.00	Broken from welding area
2.	18.90×2.90	54.81	760.00	Broken from welding area

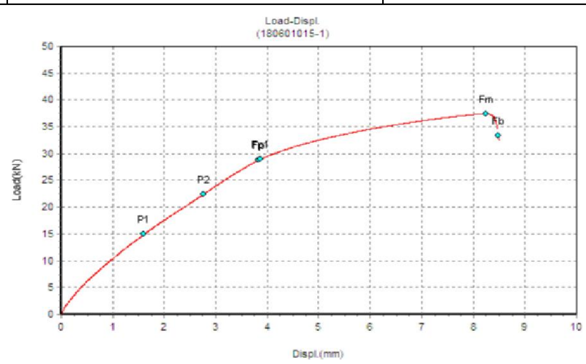
P1 : PROPOTIONALITY LIMIT
P2 : ELASTIC LIMIT
Fe : ELASTIC STRENGTH
Fp1 : YIELD STRENGTH POINT
Fm : ULTIMATE OR MAXIMUM LOAD POINT
Fb : BREAKING OR FRACTURE OR RUPTURE POINT



Test coupon-02

Table 5.5 Tensile test for test coupon-02

Tensile Test				
SampleID	Specimen Size (width×Thickness) mm	Cross-sectionalArea (mm2)	Tensile strengthN/mm2	Location of Fracture
1.	18.90×2.90	54.81	682.00	Broken area From welding
2.	18.90×2.90	54.81	689.00	Broken area from welding



Test coupon-03

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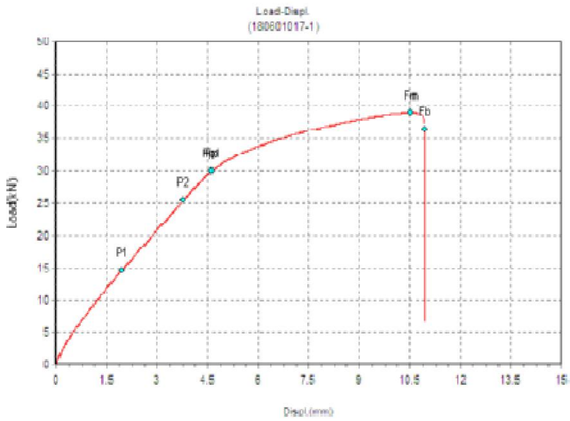
Table 5.6 Tensile test for test coupon-03

Tensile Test				
SampleID	Specimen Size (width×Thickness) Mm	Cross-sectional Area(mm2)	Tensile strengthN/mm2	Location of Fracture
1.	18.90×2.90	54.81	703.00	Broken area from welding
2.	18.80×2.90	54.52	722.00	broken area From welding



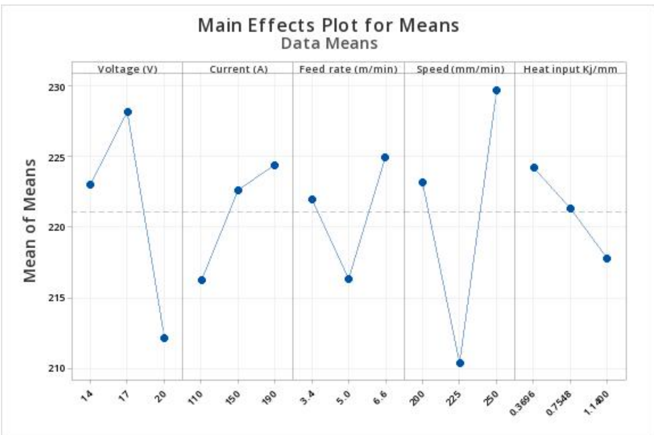
5.3 Taguchi Method Result

Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The cutting force is considered as the quality characteristic with the concept of "the larger-the-better". The S/N ratio for the larger-the-better is:

$$S/N = -10 *\log(\Sigma(Y^2)/n))$$

Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by taking into consideration above Eqn. with the help of software Minitab 17.

Analysis of Variance (ANOVA) Results for Hardness:



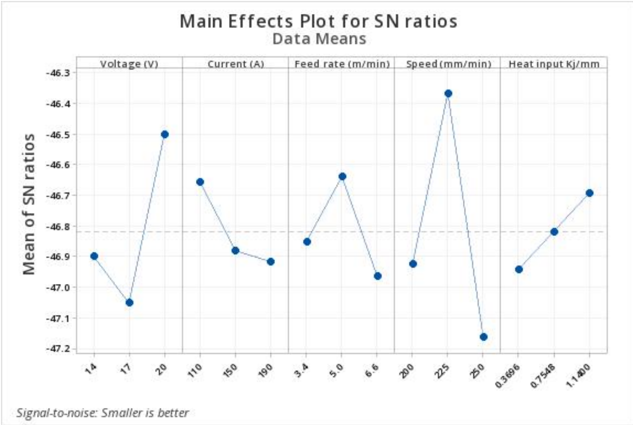
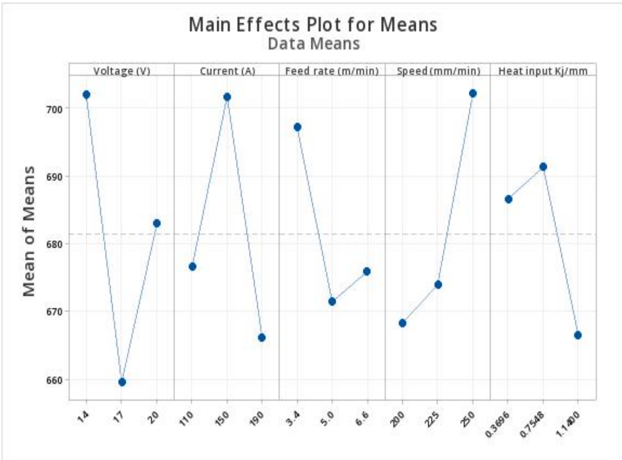


Figure 5.2. Main effect plot for SN ration for hardness

The above graph Shows that the Main effect plot for SN ration for hardness.

Taguchi Analysis: Tensile Strength (MPa) versus Voltage (V), Current (A), Feed rate (m/min), Speed(mm/min), Heat input Kj/mm

Analysis of Variance (ANOVA) Results for Tensile Strength



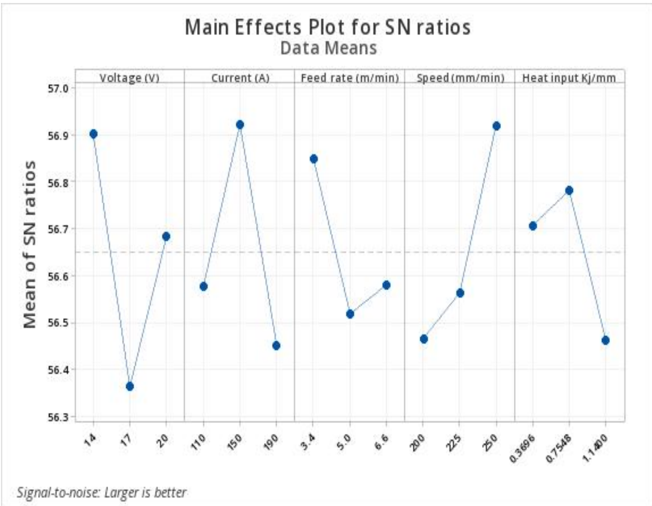


Figure 5.3. Main effect plot for SN ration for tensile strength

The above graph shows the Main effect plot for SN ration for tensile strength.

S.NO.	EXPERIMENTAL OUTCOMES	TAGUCHI OUTCOMES	% RELATIVE ERROR
1	180	180	0
2	185	185	0
3	192	192	0
4	193	193	0
5	198	198	0
6	202	201	0.497512438
7	203	202	0.495049505
8	205	203	0.985221675
9	207	205	0.975609756

Table 5.7: Comparison of Experimental Outcomes and Taguchi Outcomes (Hardness Test)

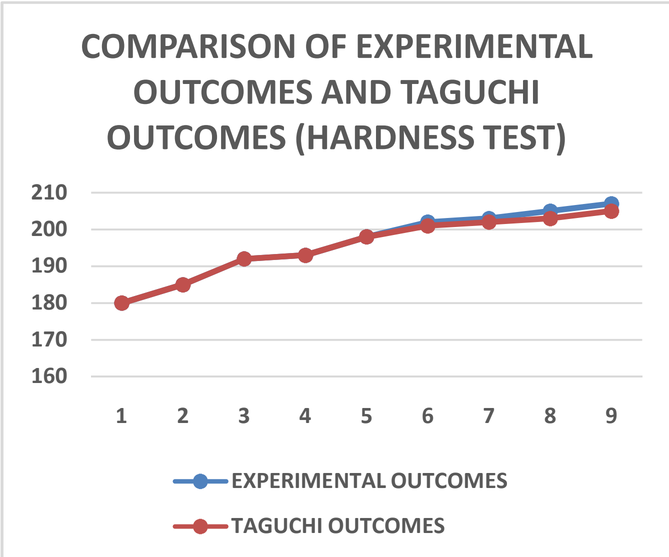


Figure 5.4: Comparison of experimental outcomes and Taguchi outcomes(Hardness Test)

Table 5.8: Comparison of Experimental Outcomes and Taguchi Outcomes (Tensile Test)

S.NO.	EXPERIMENTAL OUTCOMES	TAGUCHI OUTCOMES	% RELATIVE ERROR
1	689	703	1.991465149
2	701	705	0.567375887
3	703	710	0.985915493
4	711	711	0
5	713	713	0
6	721	721	0
7	722	722	0
8	759	759	0
9	760	760	0

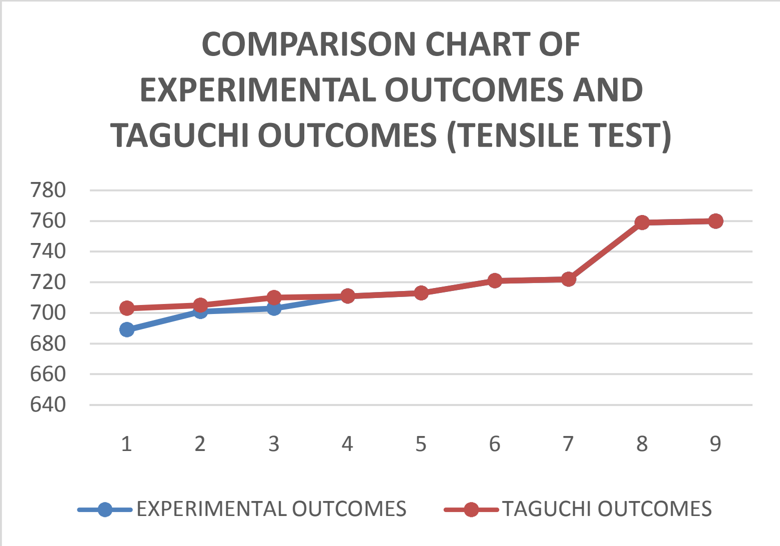


Figure 5.5: Comparison of experimental outcomes and Taguchi outcomes (Tensile Test)

Table 5.9: Results of Verification Experiment.

Condition Description	Initial set of parameters		Optimized welding parameters	
	UTS (N/mm^2)	Hardness (VHN)	UTS (N/mm^2)	Hardness (VHN)
Level	A1B1CAD1E1	A1B2C2D2E3	A1B1CAD1E2	A1B2C2D2E3
Response obtained	760	180	760	180

Form the table 5.9; one can observe that, the optimized parameters have considerable effect on the response variables i.e. Ultimate Tensile Strength (UTS) andhardness of JT Steel. Ultimate Tensile Strength(UTS) was at 760 N/mm^2, the minimum hardness has been 180 VHN.

VI. CONCLUSION AND FUTURE SCOPE

On the basis of this comparative investigation for welding JT grade with three fillers (ER308L,ER309L and ERNiCrMo-3), following conclusions can be made:

6.1. ER308L

1 While using ER308L as filler wire, HAZ showed maximum hardness for low heat input and minimum hardness for medium heat input. Weld area showed maximum hardness for lowheat input.

2 The maximum UTS value for JT grade is 700 N/mm^2 and achieved UTS after welding was760 N/mm^2 at low heat input.

3 With increase in heat input, hardness of heat affected zone is increasing while hardness isdecreasing in the weld area.

6.2. ER309L

1 While using ER309L as filler wire, HAZ showed maximum hardness at low and high heatinput. But weld area showed maximum hardness at low heat input level.

2 With increase in heat input, hardness of heat affected zone is approximately constant anddecreasing in weld area.

3 Maximum tensile strength of 713 N/mm^2 is possible at low heat input.

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6.3. ERNiCrMo-3

1. While using ERNiCrMo-3 as filler wire, maximum hardness is obtained in the HeatAffected Zone and weld area both at low heat input.
2. With increase in heat input, hardness of heat affected zone and weld area is decreasing
3. Maximum tensile strength of 721 N/mm^2 is obtained at low heat input.

Taguchi Method Optimization:

The experiment designed by Taguchi method fulfils the desired objective. The all possible values of have been calculated by using MINITAB 17.0 software. Analysis of variance (ANOVA) helps to find out the significance level of each parameter. The optimum value was predicted using MINITAB-17 software.

In this work the optimization of the process parameters for Gas Metal Arc welding of JT Steel with larger Ultimate Tensile Strength and hardness has been reported. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and Analysis of Variance (ANOVA) were used for the optimization of weldingparameters and it is found that;

i) optimum condition for maximum UTS is (A1B1CAD1E2) i.e. Voltage (V)=14, Current (A)=110, Feed rate (m/min)=3.4, Speed(mm/min)=250, Heat input (Kj/mm)=0.7548

ii) optimum condition for maximum hardness is (A1B2C2D2E3) i.e. Voltage (V)=14, Current (A)=150, Feed rate (m/min)=5, Speed(mm/min)=225, Heat input (Kj/mm)=1.14

ANOVA for UTS shows that current is the most significant factor, followed by gas flow rate. ANOVA for hardness indicates that gas flow rate influences most significantly, followed by current. Conformation experiment was also conducted andverified the effectiveness of the Taguchi optimization method.

6.4. Future Scope

To improve the experimental results from this work some future work can be made:

- Taguchi method can be perform a welding of GMAW experiment and optimize the process based on the weld parameters. An array of three levels was used to study the relationships between the weld input parameters (voltage [V], weld speed [mm/min] and weld torch angle [°]) and the response parameters such as weld ultimate transversal tensile strength [MPa] and the geometrical parameters (reinforcement [mm], width [mm] and penetration [mm]).
- The welding speed is the most influent parameter related with the geometrical parameters of the weld, but for the ultimate transversal tensile strength, the angle of the weld torch became the most significant. So we can optimize the welding strength at different weld torch angle [°].

VII. ACKNOWLEDGEMENT

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